Backlash compensation

SIMATIC S7-1500

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1 Backlash and interpolatory compensation

With this application example, mechanical lots as well as position-dependent measuring system errors can be corrected.

1.1 Backlash compensation

High-precision machines (e.g. CNC milling) are used not only for requirements such as ...
- low friction or
- less wear,
- the requirement with as little mechanical backlash as possible.

The mechanical backlash is direction-dependent and falsifies the traverse path for axes or leadscrews.

This mechanical backlash can be positive or negative:

Figure 1-1:

**Positive backlash**

![Positive backlash diagram]

Figure 1-2:

**Negative backlash**

![Negative backlash diagram]
Mechanical backlashes falsify the traverse path of axes/leadscrews with indirect measuring systems. When the direction is reversed, the axis moves too short or too far by the amount of the lots. The mechanics and the associated encoder are also affected.

If the encoder is ahead of the mechanics, the measured actual position is reached earlier, so the travel distance of the machine is actually too short.

To avoid defects on the workpiece, this backlash can be compensated with the function block described here in an S7-1500 (from firmware V2.5).

1.2 **Interpolatory compensation**

With interpolatory compensation, position-dependent dimensional deviations such as

- Leadscrew and measuring system errors,
- slack
- and angularity errors can be corrected.

![Figure 1-3 Angle and slack compensation](image)

The correction values are measured during commissioning and stored position-related in a compensation table. During operation, the position value of the corresponding axis is corrected by linear interpolation between the interpolation points.

Since these dimensional deviations have a direct effect on the accuracy of workpiece machining, they must be compensated for by corresponding position-dependent correction values. The correction values are determined on the basis of the measured error curve and entered into the controller during commissioning in the form of so-called compensation tables. A separate table must be created for each compensation type.
1.3 Function of the Application Example

The compensation of the backlashes can be done mechanically on the one hand or mathematically on the other hand. Since mechanical compensation would greatly increase machine wear and tear and is also difficult to implement, mathematical compensation is often used.

1.3.1 How the backlash compensation works

The component of this application example computationally compensates

- on the controller the mechanical play between a drive and a moving machine part or
- the play between an encoder and a moving machine part.

The traverse path is corrected by adding or subtracting the amount of the lots accordingly in the module of the application example. The technology object in the SIMATIC S7-1500 CPU then calculates with the corrected encoder values.

1.3.2 How the backlash Interpolatory compensation works

With the Interpolatory compensation you can compensate position depending on measuring system errors.

This additional compensation value can be used for interpolating compensation, e.g. leadscrew compensation.

The travel distance to be compensated determined with the start and end position is divided into several (number depending on the error curve shape) sections (see following figure). The actual positions, which limit these sections, are referred to in the following as "support points". The corresponding correction value must be entered for each calibration point during commissioning. Between 2 interpolation points, the correction value acting there is formed by a linear interpolation, i.e. adjacent interpolation points are connected by a distance.

Figure 1-4 Linear interpolation between the interpolation points

Note

The compensation table should be structured so that the correction value = 0 at the reference point.
1.4 Components used

The following hardware and software components were used to create this application example:

Table 1-1

<table>
<thead>
<tr>
<th>Components</th>
<th>Quantity</th>
<th>Article number</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU 1516-3 PN/DP</td>
<td>1</td>
<td>6ES7 516-3AN00-0AB0</td>
<td>All S7-1500 CPUs from FW V2.5 are supported.</td>
</tr>
<tr>
<td>STEP 7 Professional</td>
<td>1</td>
<td>6ES7822-1AA04-0YA5</td>
<td>from V15</td>
</tr>
</tbody>
</table>

This application example consists of the following components:

Table 1-2

<table>
<thead>
<tr>
<th>Components</th>
<th>File name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project file</td>
<td>109766673_S7-1500_BacklashCompensation_PROJ_v10.zip</td>
</tr>
<tr>
<td>Reference document</td>
<td>109766673_S7-1500_BacklashCompensation_DOC_v10_en.pdf</td>
</tr>
</tbody>
</table>
2 Engineering

2.1 FB „BacklashCompensation“

The “BacklashCompensation” block corrects the encoder data G1_XIST1 mathematically. The corrected data is then used in the user program for further use.

The main functionality of the device is lot compensation. However, a further value can be compensated by a further module (see section 2.5.4). This means that the application example contains several functions for compensation:

- backlash compensation
- an optional additional compensation value (interpolatory compensation)

With interpolatory compensation, it should be noted that the correction values are measured during commissioning and stored position-related in a compensation table. During operation, the corresponding axis is corrected by linear interpolation between the interpolation points.

A separate table must be created for each type of compensation (leadscrew or sag compensation). The values of the compensation table are linked to the block in the form of a DB.

2.1.1 Interface description

The “BacklashCompensation” block has the following input and output interfaces:

Figure 2-1: BacklashCompensation

<table>
<thead>
<tr>
<th>BacklashCompensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bool enable</td>
</tr>
<tr>
<td>TO_PositioningAxis axis</td>
</tr>
<tr>
<td>LReal backlashDistance</td>
</tr>
<tr>
<td>LReal additionalCompensation Value</td>
</tr>
<tr>
<td>UInt activationCycles</td>
</tr>
<tr>
<td>UInt encoderNumber</td>
</tr>
<tr>
<td>UInt encoderOffsetG1_XIST1</td>
</tr>
<tr>
<td>UDInt encoderIncrements</td>
</tr>
<tr>
<td>UDInt encoderPosition</td>
</tr>
<tr>
<td>LReal totalCompensation Increments</td>
</tr>
<tr>
<td>LReal totalCompensation Value</td>
</tr>
<tr>
<td>LReal BacklashCompensation Value</td>
</tr>
<tr>
<td>DInt busy</td>
</tr>
<tr>
<td>Bool active</td>
</tr>
<tr>
<td>Bool error</td>
</tr>
<tr>
<td>Word errorId</td>
</tr>
</tbody>
</table>
### Table 2-1 Parameter description of the "BacklashCompensation" block

<table>
<thead>
<tr>
<th>Name</th>
<th>P type</th>
<th>Data type</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>enable</td>
<td>IN</td>
<td>Bool</td>
<td>Activation/deactivation of the block</td>
</tr>
<tr>
<td>axis</td>
<td>IN</td>
<td>TO_PositioningAxis</td>
<td>TO axis: A TO_SynchronousAxis can also be transferred.</td>
</tr>
<tr>
<td>backlashDistance</td>
<td>IN</td>
<td>LReal</td>
<td>Positive or negative backlashes</td>
</tr>
<tr>
<td>additional CompensationValue</td>
<td>IN</td>
<td>Real</td>
<td>(optional, visible after module extension)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Additional, additive compensation value that acts directly</td>
</tr>
<tr>
<td>activationCycles</td>
<td>IN</td>
<td>UInt</td>
<td>Enter the number of call cycles to deactivate or activate the lots (linear function) to avoid jumps in the actual value. Default value: 1</td>
</tr>
<tr>
<td>encoderIncrements</td>
<td>OUT</td>
<td>DInt</td>
<td>Encoder value without compensation</td>
</tr>
<tr>
<td>encoderPosition</td>
<td>OUT</td>
<td>LReal</td>
<td>Encoder position without compensation (from cycle before)</td>
</tr>
<tr>
<td>totalCompensationIncrements</td>
<td>OUT</td>
<td>DInt</td>
<td>Active total correction value in increments that is compensated</td>
</tr>
<tr>
<td>totalCompensationValue</td>
<td>OUT</td>
<td>LReal</td>
<td>Active total correction value to be compensated (unit depends on TO configuration)</td>
</tr>
<tr>
<td>backlashCompensationValue</td>
<td>OUT</td>
<td>LReal</td>
<td>Proportional correction value for lot compensation</td>
</tr>
<tr>
<td>busy</td>
<td>OUT</td>
<td>Bool</td>
<td>FB is executed</td>
</tr>
<tr>
<td>active</td>
<td>OUT</td>
<td>Bool</td>
<td>A correction value &lt;&gt; 0 is active.</td>
</tr>
<tr>
<td>Error</td>
<td>OUT</td>
<td>Bool</td>
<td>error = TRUE, means that the FB was parameterized incorrectly or that an error occurred during compensation.</td>
</tr>
<tr>
<td>errorId</td>
<td>OUT</td>
<td>WORD</td>
<td>Error number (see section 2.3)</td>
</tr>
</tbody>
</table>

After expanding the block view, additional parameters are available:
### Table 2-2 additional Parameter description of the "BacklashCompensation" block

<table>
<thead>
<tr>
<th>Name</th>
<th>P-Typ</th>
<th>Datentyp</th>
<th>Hinweis</th>
</tr>
</thead>
<tbody>
<tr>
<td>encoderNumber</td>
<td>IN</td>
<td>UInt</td>
<td>Enter the encoder number (1..4) at which the backlashes are to be compensated. Encoders 2..4 are only supported for T-CPU's. Default value: 1</td>
</tr>
<tr>
<td>encoderOffset G1_XIST1</td>
<td>IN</td>
<td>Int</td>
<td>IO Address offset of G1_XIST1 of the PROFIdrive telegram (3, 4, 5, 6, 105, ...) in Bytes Default value: 12 Bytes (for Siemens Telegram 105)</td>
</tr>
</tbody>
</table>

**NOTE**
The encoder values G1_XIST1 are changed directly and are written to the TO. So the values for the TO are the corrected values (with the corrected lots) and not the original ones.
2.2 FC "GetYValueFromCharacteristic"

With the function "GetYValueFromCharacteristic" position-dependent dimensional deviations can be corrected interpolating. This function can be used by switching the corresponding FC "GetYValueFromCharrracteristic" before the FB "Backlashcompensation".

This additional correction value has a direct effect and is only "smoothed" when switching on and off (enable), depending on the input parameter "activationCycles".

The travel distance to be compensated determined with the start and end position is divided into several (number depending on the error curve form) sections. The actual positions, which limit these sections, are referred to in the following as "support points". The corresponding correction value must be entered for each calibration point during commissioning. Between 2 interpolation points, the correction value acting there is formed by a linear interpolation, i.e. adjacent interpolation points are connected by a distance.

The correction values (compensation table) are connected as DB to the FC "GetYValueFromCharacteristics".

Figure 2-2: GetYValueFromCharacteristic

<table>
<thead>
<tr>
<th>Name</th>
<th>P type</th>
<th>Data type</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>xValue</td>
<td>IN</td>
<td>LReal</td>
<td>Current position</td>
</tr>
<tr>
<td>characteristic_DB_NUMBER</td>
<td>IN</td>
<td>UInt</td>
<td>Specifies the DB that contains the compensation table.</td>
</tr>
<tr>
<td>yValue</td>
<td>OUT</td>
<td>LReal</td>
<td>Output of the compensated value</td>
</tr>
</tbody>
</table>

The output "yValue" has to be connected to the input „additdional CompensatiponValue“ of the FB „BacklashCompensation“.

(See chapter: 2.5.4)
2 Engineering

2.3  Error description FB "BacklashCompensation"

Table 2-4 Description of the FB error numbers "BacklashCompensation".

<table>
<thead>
<tr>
<th>errorId</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No error</td>
</tr>
<tr>
<td>8050</td>
<td>Incorrect encoder number or encoder is not activated</td>
</tr>
<tr>
<td>8236</td>
<td>The encoder is connected via an optimized data block. Deactivate the &quot;Optimized block access&quot; at the interface DB of the respective encoder.</td>
</tr>
</tbody>
</table>

2.4  Error description FC "GetYValueFromCharacteristic"

Table 2-5 Description of the return value of the FC "GetYValueFromCharacteristic".

<table>
<thead>
<tr>
<th>Ret_Val</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No error</td>
</tr>
<tr>
<td>8001</td>
<td>The compensation table has an invalid parameter.</td>
</tr>
<tr>
<td>8154</td>
<td>The compensation table (data block) has an incorrect data type &lt;&gt; &quot;typeCharacteristic&quot;.</td>
</tr>
<tr>
<td>8389</td>
<td>The compensation table (data block) is invalid or the DB_NUMBER does not exist.</td>
</tr>
<tr>
<td>8130..8155</td>
<td>See online help &quot;DB_ANY_TO_VARIANT: Convert DB_ANY in VARIANT&quot;</td>
</tr>
</tbody>
</table>
2.5 Integration into the user project

2.5.1 General requirements

The FB “BacklashCompensation” must be called in the OB “MC-PreServo”, since only here the encoder increments “G1_XIST1” can be corrected mathematically. The TO then calculates the current position <axis>.StatusSensor[].Position in the MC servo on the basis of the corrected encoder increments.

2.5.2 Requirements for the interpolatory compensation

If interpolating compensation is to be carried out, a corresponding table must be stored. The structure is as follows:

<table>
<thead>
<tr>
<th>LeadScrewCompensationCharacteristic</th>
<th>Name</th>
<th>Data type</th>
<th>Start value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>minValue</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>maxValue</td>
<td>Real</td>
<td>50.0</td>
</tr>
<tr>
<td>3</td>
<td>[value0]</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>[value1]</td>
<td>Real</td>
<td>20.0</td>
</tr>
<tr>
<td>5</td>
<td>[value2]</td>
<td>Real</td>
<td>25.0</td>
</tr>
<tr>
<td>6</td>
<td>[value3]</td>
<td>Real</td>
<td>50.0</td>
</tr>
<tr>
<td>7</td>
<td>[value4]</td>
<td>Real</td>
<td>50.0</td>
</tr>
<tr>
<td>8</td>
<td>[value5]</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>9</td>
<td>[value6]</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>10</td>
<td>[value7]</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>11</td>
<td>[value8]</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>12</td>
<td>[value9]</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>13</td>
<td>[value0]</td>
<td>Real</td>
<td>1.0</td>
</tr>
<tr>
<td>14</td>
<td>[value1]</td>
<td>Real</td>
<td>0.5</td>
</tr>
<tr>
<td>15</td>
<td>[value2]</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>16</td>
<td>[value3]</td>
<td>Real</td>
<td>-0.5</td>
</tr>
<tr>
<td>17</td>
<td>[value4]</td>
<td>Real</td>
<td>2.0</td>
</tr>
<tr>
<td>18</td>
<td>[value5]</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>19</td>
<td>[value6]</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>20</td>
<td>[value7]</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>21</td>
<td>[value8]</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>22</td>
<td>[value9]</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>23</td>
<td>minValue</td>
<td>Real</td>
<td>0.0</td>
</tr>
<tr>
<td>24</td>
<td>maxValue</td>
<td>Real</td>
<td>50.0</td>
</tr>
<tr>
<td>25</td>
<td>minValue</td>
<td>Real</td>
<td>-0.5</td>
</tr>
<tr>
<td>26</td>
<td>maxValue</td>
<td>Real</td>
<td>2.0</td>
</tr>
<tr>
<td>27</td>
<td>minIndex</td>
<td>UInt</td>
<td>4</td>
</tr>
</tbody>
</table>

Note: The value of minValue must be smaller than maxValue.

Furthermore, the application example contains two subfunctions that are located in the “Subfunctions” folder and serve as a workaround. These functions are used to make the PLC data type “Characteristic → typeCharacteristic” known in the user program (see online help “DB_ANY_TO_VARIANT: Convert DB_ANY in VARIANT”). These blocks must be copied into the user program, but not called.
Encoder connection on the TO via data block

Note
If a data block is selected as encoder interface, then this interface DB must not be optimized (see example project, here the encoder connection is made via data block, so that the backlash compensation can also be simulated in the example project).

2.5.3 Call structure

The following figure shows the call structure of the user program:

Figure 2-5 Call Structure in the User Program

- Call Backlash Compensation
- MC-PreServo [OB67]
- MC-Servo [OB91]
- Technology object
- Subfunctions
  - FCdummy [FC1]
  - FCdummy2 [FC2]
2.5.4 Exemplary integration of sag compensation

With the function FC "GetYValueFromCharacteristic" measuring system errors can be compensated with an interpolation. The following example shows the integration of the FC and the FB to compensate a leadscrew error.

Figure 2-6 Example integration leadscrew error compensation

The basic functionality of the application example is backlash compensation. However, the user has the option of switching an additional compensation value at the "backlashCompensation" block at the "additionalCompensationValue" input, which is calculated interpolating.

The additional compensation value is calculated outside the block, in this example in network 1 (Netzwerk 1).

First, the actual position for the leadscrew compensation is calculated:

Actual position of leadscrew compensation = actual position TO - last leadscrew compensation value

The function "GetYValueFromCharacteristic" interpolates the corrected actual position from the data block in which the compensation table is stored. The output value is then connected to the "backlashCompensation" block.

Note
It should be noted that the actual position corresponds to that of the last cycle.
2.5.5 Operation of the Program

The functionality of the application example can be tested using a simulated controller. For this a controller is selected and the program "Backlash compensation" is loaded.

Subsequently the application example is controlled via the instance DB "ProgMain_DB".

The following variables have to be set to control the FB:

Table 2-6 Control of the variables via the instance DB

<table>
<thead>
<tr>
<th>Tag</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>power</td>
<td>TRUE</td>
</tr>
<tr>
<td>reset</td>
<td>Rising edge</td>
</tr>
<tr>
<td>home</td>
<td>TRUE</td>
</tr>
<tr>
<td>enablePos</td>
<td>TRUE</td>
</tr>
</tbody>
</table>

Figure 2-7 Tags overview

Now the axis moves and the block FB "BacklashCompensation" can be tested. The DB "ProgPreServo_DB" is called for this purpose:

The values "actPostion" and "statActPostion" should change continuously. This indicates that the axis is moving and that the current position is changing.
In order to test the "BacklashCompensation" block, the block must first be activated via "enable". Now any value for compensation can be entered at the "backlashDistance" input.
3 Appendix

3.1 Service and support

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We support you with our globally available training courses for industry with practical experience, innovative learning methods and a concept that’s tailored to the customer’s specific needs.
For more information on our offered trainings and courses, as well as their locations and dates, refer to our web page:
www.siemens.com/sitrain

Service offer

Our range of services includes the following:
- Plant data services
- Spare parts services
- Repair services
- On-site and maintenance services
- Retrofitting and modernization services
- Service programs and contracts
You can find detailed information on our range of services in the service catalog web page:
support.industry.siemens.com/cs/sc

Industry Online Support app

You will receive optimum support wherever you are with the "Siemens Industry Online Support" app. The app is available for Apple iOS, Android and Windows Phone:
support.industry.siemens.com/cs/ww/en/sc/2067
3 Appendix

3.2 Links and literature

Table 3-1

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3.3 Change documentation

Table 3-2

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